Defining the Target Treatment Area for Thermal Remediation

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Background. Over the last 20 years, I have had the pleasure of doing technical support for more than 20 Superfund sites where thermal remediation has been completed. All of them have been successful in removing a significant amount of contaminant mass – and a large percentage of the mass within the treatment area - from the subsurface. Some of the larger sites include:

Visalia - ~ 1 M lbs wood treatment chemicals recovered

Former Williams Air Force Base - ~ 2.4 M lb jet fuel recovered

Solvent Recovery Services of New England - ~ 500,000 lbs waste oils recovered

But in terms of effectively moving the site toward closure, some of these sites are more successful than others. Based on experience at the sites where I have been involved, the difference between effectively moving the site toward a final remedy or closure - or not - has been largely dependent on whether or not essentially all of the source zone was treated.

At Southern California Edison's Visalia Pole Yard, the NAPL source area within the saturated zone was treated by steam injection to recover the creosote NAPL. When NAPL was no longer being recovered, steam injection was terminated and pump & treat (P&T) continued for 4 years until groundwater cleanup criteria were met. Not only were they then able to delist the site from the NPL, they were also able to dismantle the P&T system that was costing them ~ $1M/year to operate.

At another Superfund site, one source zone (mainly PCE) was successfully remediated using Electrical Resistance Heating

(ERH), as can be seen in the source zone well that continues to show concentrations that are not indicative of DNAPL presence. However, other source zones to the north and south have recontaminated sections of the thermal treatment area.

This source zone well shows the expected increase in groundwater concentrations during remediation, then a rapid decrease once the DNAPL is recovered. Current PCE concentrations ~ 500 μg/L are not indicative of DNAPL.

The Northern Treatment Area Deep Well was initially below the thermal treatment area, as it did not contain significant PCE concentrations. The actual location of the source zone creating the plume seen in the graph is not known.

PCE concentrations in the Southern Treatment Area Well initially indicated the presence of PCE DNAPL, which was successfully recovered during ERH. However, increasing concentrations post-treatment are coming from a known PCE source slightly south of the treatment area that is being treated by SVE.

NAPLs migrate! I'm commonly told that NAPLs in the subsurface are not migrating, thus they do not pose a risk. I now have definite proof of continued NAPL migration at two different sites. At the former Williams Air Force Base, at the time that the steam enhanced extraction (SEE) system was planned, it was believed that the jet fuel at depth was largely contained within the light blue area shown (with the exception of well W-37 to the southeast). However, as the system was installed, LNAPL was found to extend to the edges of the light blue area, which changed the design of the SEE system from outside-in steam injection to inside-out (perimeter wells were extraction wells). Subsequent borings determined that the

LNAPL had spread considerably beyond where initially characterized to be, as shown in the dark blue. To the east the extent of LNAPL at this depth is still not fully defined. More than 2 million pounds of jet fuel were recovered by SEE, however, it is estimated that a similar amount remains in the subsurface surrounding the areas that were treated.

The DNAPL reconnaissance investigation at this site which involved sonic soil cores at ~ 40 foot spacings and 'multiple lines of evidence' (PID, FLUTe ribbon, and soil analytical samples) determined the DNAPL extent in the saturated zone as the green line. The pink-colored areas show where mobile DNAPL was found, based on flow of DNAPL into wells and soil concentrations. More than 10 years after the DNAPL recon was completed, DNAPL migrated into a well to the north of the former manufacturing area, ~ 400 feet from what was believed to be the extent of DNAPL. Groundwater samples from the monitoring well had been forecasting the approaching DNAPL.

It's not uncommon for NAPLs to continue migrating. Recent characterization data of NAPL extent is required to ensure that essentially all of the NAPL contaminated area is within the thermal treatment area. One option is to install borings/wells as the system is being designed. Another option is to complete the characterization after the system is designed and as the system is being constructed. This option has resulted in significant increases in the treatment area, requiring significant redesign, particularly of energy requirements. These options have an advantage in that spacings between borings/wells for remediation are often closer than boring spacings used for characterization.

What type of data should be used to define NAPL area?
For this Superfund site, a potential NAPL area was delineated based on groundwater results where VOCs were detected at

> 1% of their effective solubility. The probable NAPL area was delineated based on the detection of alcohols in groundwater. Alcohols were believed to be degradation products of the VOCs that were only detectable close to NAPL, as they were then biodegraded themselves. The thermal treatment zone was delineated based on where NAPL was observed in soil cores, with substantial help from oil red dyes.

Was this definition of the thermal treatment area adequate?

Yes – This graph of influent concentrations to the P&T system shows that when in situ thermal treatment (ISTR) ended, the influent concentrations decreased substantially, and continued to decrease overall. Two years after thermal treatment ended, chlorinated VOCs are no longer found in the influent, and petroleum hydrocarbon VOCs have decreased to less than 10 kg/year. This is a good indication that essentially all the NAPL was success removed from the source zone. The criteria of visible NAPL was used successfully to delineate the NAPL-contaminated area.

Thus, defining the area to be treated by thermal remediation – the source zone - is critical to the success of a thermal remediation project. Generally the focus of an in situ thermal remediation is the source zone, defined as the area containing nonaqueous phase liquids (NAPL). The cost of thermal remediations are directly proportional to the area or volume to be treated, thus it is desirable to keep the treatment area and volume to a minimum to control costs. On the other hand, leaving NAPL-contaminated areas outside of the treatment zone reduces the effectiveness of the remediation by leaving behind a continuing source of groundwater contamination. Also, NAPLs adjacent to but outside of the treatment area will continuously re-contaminate the treated area. Thus, defining the NAPL contaminated area is critical.

Approach. Different criteria and different characterization approaches have been used to define the source zone for thermal treatment at different sites. It is well known that the delineation of many different NAPLs in the subsurface is difficult, and 'multiple lines of evidence' are generally used, including observation of soil cores and soil sample analytical results, PID screening, FLUTe ribbon or oil red dye testing, as well as groundwater concentrations. This presentation will discuss NAPL characterization efforts, as well as cases where NAPL migration was documented to continue long after the discharge of the NAPL to the subsurface was terminated.

Not all NAPLs are equally easy to see. The top picture shows TCE, a clear liquid, recovered from a well. The second picture shows waste oil LNAPL recovered from a waste oil site. But even dark colored NAPLs can be difficult to see in soil. Dye tests have been successfully used to observe waste oil NAPL and jet fuel in soils.

Lessons Learned. Long term benefits in terms of being able to reduce plume containment efforts and treatment have been realized at sites where in situ thermal remediation has been used to effectively remediate NAPL source zones. After thermal remediation was completed, the Visalia Pole Yard Superfund site was delisted from the NPL, able they were able to shut down the P&T system they had been operating for years, and which they would have had to operate in perpetuity had the source zone not been eliminated. The SRSNE site was able to reduce their onsite treatment requirements of extracted groundwater. In order to realize these benefits, essentially all of the source zone must be treated, which makes characterization to determine the source zone critical. NAPL zone characterization at different sites have shown that in addition to the well-known difficulties of detecting NAPL, continued NAPL migration may make the extent of NAPL even more difficult to determine.

When determining the extent of the area to be treated, the long term benefits should be considered. When applied to all the source zone(s) aggressively thermal remediation can hopefully move many sites much closer to completion and delisting, and thus suitable for redevelopment.

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